International Journal of Automation and Power Engineering, 2012, 1: 77-82
Published Online June 2012

www.ijape.org

New Modeling of UPFC for Power Flow Study and Setting Parameters to Increase Voltage Level and Reduce Power Losses

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(Abstract) The Unified Power Flow Controller (UPFC), is one of the most complex Flexible alternating-current transmission systems (FACTS) devices in a power system. The UPFC is the shunt-series device that provides power flow control together with separate voltage control. The objective of this paper is propose a UPFC model that can be incorporated into existing MATLAB based MATPOWER for power flow studies. Power flow is the analysis to determine the steady-state magnitude and angle voltages at all buses of the power system and also the real and reactive power flows in every transmission line. The proposed model in order to increase voltage level and reduce power losses is tested on IEEE 14-bus system.

Keywords: UPFC; Injection model; Power Flow; MATPOWER; MATLAB.

1. INTRODUCTION

Nowadays, several important issues related to power system have been discussed worldwide. Some of the serious issues are the power quality, transmission loadability, congestion management, reduce power losses and voltage stability. To overcome these issues, best approach is using FACTS devices. In the late 1980s the Electric Power Research Institute (EPRI) has presented a new technology known as FACTS [1].

One of the most general FACTS devices is UPFC, which has been introduced by Gyugyi in 1991[2]. The structure of UPFC that shown in Figure 1, consisting of two "back to back" AC to DC voltage source converters (VSC) operated from a common DC link capacitor. First converter (converter 1 or shunt converter) is connected in shunt and the second converter (converter 2 or series converter) in series with the transmission line. The shunt converter is mainly used to supply active power demand of the series converter via a common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the basic function of the UPFC by injecting a voltage with controllable amplitude and phase angle in series with the line via a voltage source [3], [4].

Several papers can be found on development of UPFC steady state and dynamic models [5] - [8]. Steady state model referred as an injection model is described in [5]. This model is usually used for UPFC modeling.

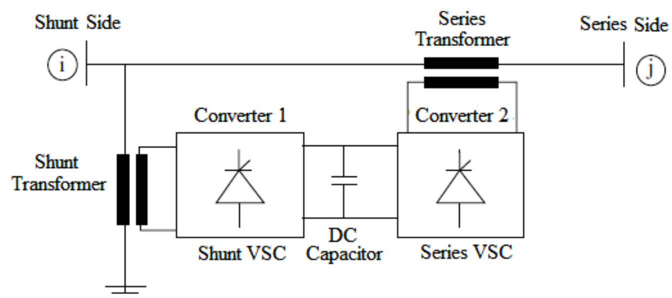

Figure 1. Structure of UPFC.

The rest of the paper is organized as follows: injection model of UPFC is described in section 2. The proposed method for UPFC modeling is presented in Section 3. Simulation results along with some observations are discussed in Section 4. In this section IEEE 14-bus test system is used for the case studies. The paper ends with a summary conclusion in the final section

2. UPFC INJECTION MODEL

To obtain UPFC injection model, it is first essential to consider the series voltage source, Fig.ure 2.

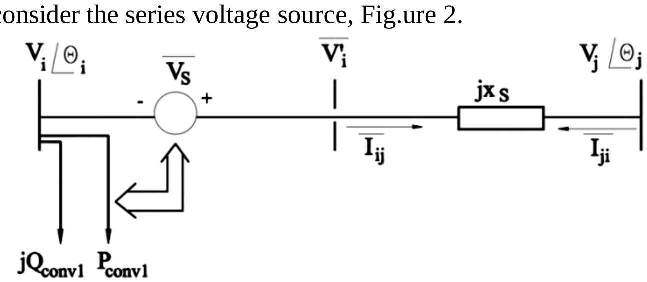

Figure 2. The UPFC electric circuit [3].

The reactance x_s describes a reactance seen from terminals of the series transformer and is equal to (in p.u. base on system voltage and base power) [3], [4]:

$$x_s = x_k r_{max}^2 \left(\frac{S_B}{S_S}\right) \tag{1}$$

$$b_s = -\frac{1}{x_s} \tag{2}$$

That

x_k: The series transformer reactance.

r_{max} : The maximum value of injected voltage amplitude (p.u.).

S_B: The system base power.

$S_S = S_{conv\,2}$: The nominal rating power of the series converter.

Voltage source connected in series is modeled with an ideal series voltage ($\overline{V_s}$) the amplitude and phase is controlled [3], [4].

$$\begin{gathered} \overline{V_s} = r\overline{V_i}e^{j\gamma} \\ 0 \leq r \leq r_{max} \\ 0 \leq \gamma \leq 2\pi \end{gathered} \tag{3}$$

That

r: The value of injected voltage amplitude (p.u.).

γ: The value of injected voltage angle.

The equations of the UPFC injection model (Figure 3) are given as [3], [4]:

$$P_{si} = -rb_sV_iV_j\, sin(\theta_i - \theta_j + \gamma) \tag{4}$$

$$Q_{si} = -rb_sV_i{}^2\, cos(\gamma) + Q_{conv\,1} \tag{5}$$

$$P_{sj} = rb_sV_iV_j\, sin(\theta_i - \theta_j + \gamma) \tag{6}$$

$$Q_{sj} = rb_sV_iV_j\, cos(\theta_i - \theta_j + \gamma) \tag{7}$$

$$\begin{aligned} P_{i1} = &-rb_sV_iV_j\, sin(\theta_i - \theta_j + \gamma) \\ &- b_sV_iV_j\, sin(\theta_i - \theta_j) \end{aligned} \tag{8}$$

$$\begin{aligned} Q_{i1} = &-rb_sV_i{}^2\, cos(\gamma) + Q_{conv\,1} - b_sV_i{}^2 \\ &+ b_sV_iV_j\, cos(\theta_i - \theta_j) \end{aligned} \tag{9}$$

$$\begin{aligned} P_{j2} = &\ rb_sV_iV_j\, sin(\theta_i - \theta_j + \gamma) \\ &+ b_sV_iV_j\, sin(\theta_i - \theta_j) \end{aligned} \tag{10}$$

$$\begin{aligned} Q_{j2} = &\ rb_sV_iV_j\, cos(\theta_i - \theta_j + \gamma) - b_sV_j{}^2 \\ &+ b_s\, V_iV_j\, cos(\theta_i - \theta_j) \end{aligned} \tag{11}$$

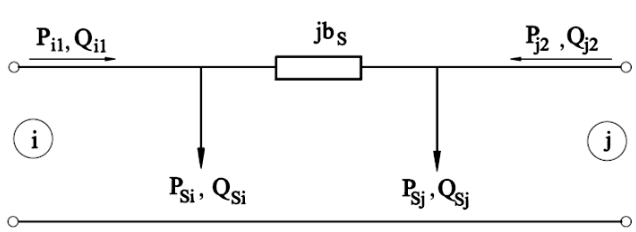

Figure 3. Injection model of the UPFC [3].

3. UPFC MODEL AND ALGORITHM

In this section we propose a new method for modeling UPFC based on injection model. The model is simple and beneficial in understanding the UPFC impact on the power system. In addition, the proposed model for modeling UPFC in the MATLAB is very efficient. Figure 4, shows the proposed model for the UPFC.

In this case UPFC can be modeled by a load at the sending bus (PQ bus, satisfy the equations 4 and 5) and an “equivalent PQ generator” at the receiving bus (PQ bus, satisfy the equations 6 and 7). Using this model, two virtual buses are added to the network.

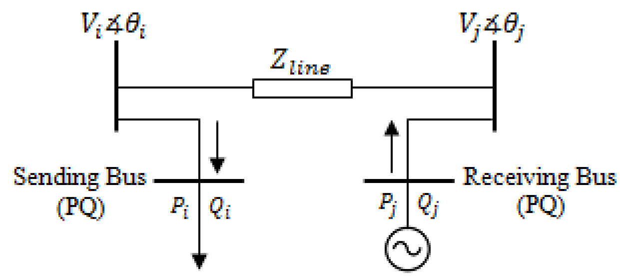

Figure 4. New load flow model.

That

$$Z_{line} = R_{line} + j(X_{line} + X_s) \tag{12}$$

Power required at the sending bus is set to the desired real and reactive powers at that bus. Reactive power is injected (in sending bus) order to achieve the specified voltage magnitude. The flowchart of power flow algorithm with/without presence of UPFC shown in Figure 5.

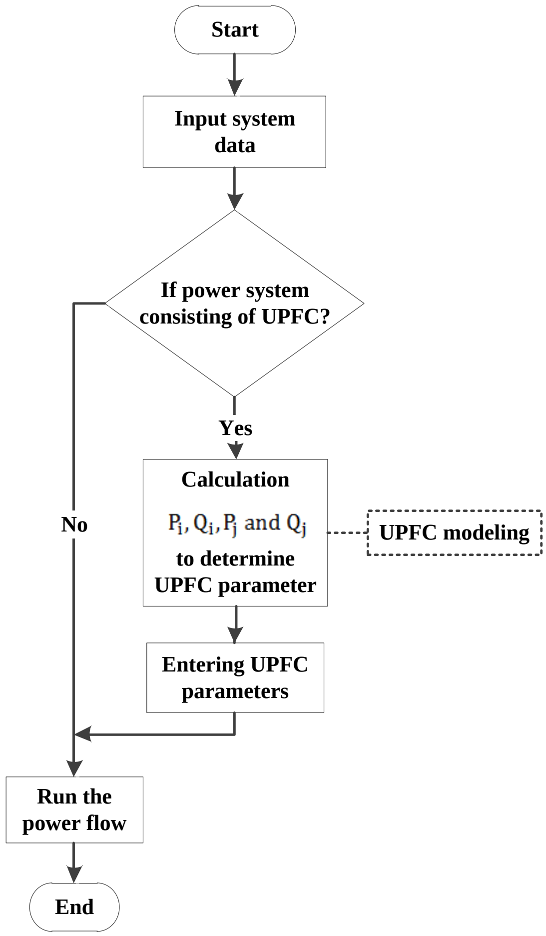

Figure 5. Power flow algorithm.

4. SIMULATION RESULTS

In this section, the UPFC parameters are set to increase voltage level and reduce power losses. The IEEE 14-bus test system is shown in Fig. 6 to demonstrate the effectiveness and validity of the proposed model. The system data is found in [9]. In this network active and reactive power of buses (load) 9, 10 and 14 are changed. The changes of power are shown in Table 1. MATPOWER, a toolbox of MATLAB, has been used for simulations and UPFC modeling [10].

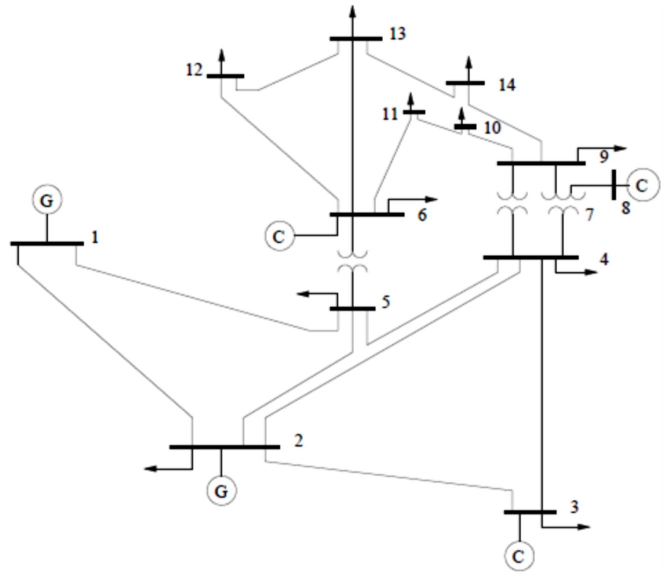

Figure 6. IEEE 14-bus test system.

Table 1. Power changes.

Bus number (Load)	Active power (MW)	Reactive power (MVar)
9	29.5→39.5	16.6→30
10	9→36	5.8→15.8
14	14.9→54.9	5→30

Table 2 shows the power flow result without presence of UPFC.

Table 2. Power Flow Result without Presence of UPFC.

Bus number	Voltage amplitude (pu)	Power losses	
		Active (MW)	Reactive (MVar)
1	1.06	8.39	25.62
2	1.045		
3	1.01		
4	0.992		
5	0.998		
6	1.07		
7	1.022		
8	1.09		
9	0.988		
10	0.98		
11	1.02		
12	1.041		
13	1.019		
14	0.904		

According to the Table 2, bus 14 as sending bus and bus 13 as receiving bus (line 13-14) are chosen for installing UPFC in order to increase voltage level of bus 14 and decrease power losses.

The UPFC parameters are given in Table 3.

TABLE I. **Table 3.** UPFC Parameters.

UPFC parameters	Value
x_k	0.01 pu
r_{max}	0.08 pu
$S_S = S_{conv\,2}$	50 MVA

The voltage magnitude of bus 14 have been shows in Figure 7 for the case when varying both the injected voltage magnitude (r) from 0.01 to 0.0.8 pu and the injected voltage angle (γ) for 0, 120 and 240 degree.

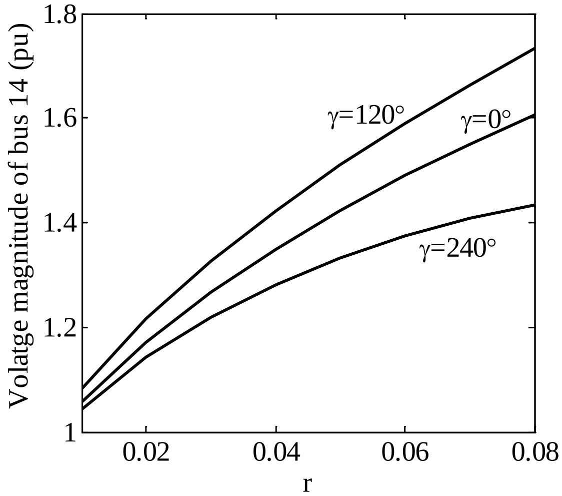

Figure 7. Voltage magnitude of bus 14 (pu).

The active power losses have been shows in Figure 8 for the case when varying both the injected voltage magnitude (r) from 0.01 to 0.0.8 pu and the injected voltage angle (γ) for 0, 120 and 240 degree.

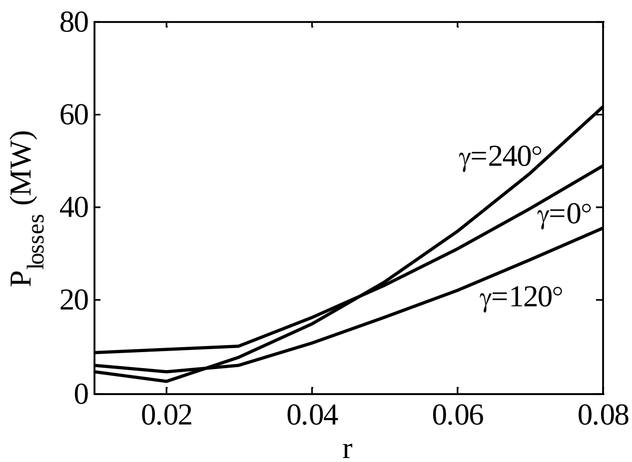

Figure 8. Active power losses (MW).

Also the voltage magnitude of bus 14 have been shows in Figure 9 for the case when varying both injected reactive power ($Q_{conv\,1}$) from -100 to 100 MVar and the injected voltage magnitude (r) from 0 to 0.08 (assuming $\gamma = 120°$).

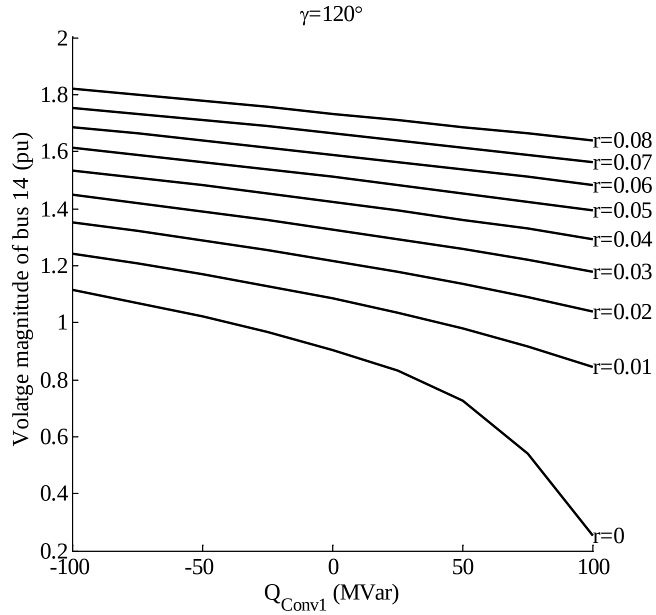

Figure 9. Voltage magnitude of bus 14 (pu),$\gamma = 120°$.

Power flow results for UPFC Installed at bus 14 (line 13-14) for various r and γ are given in Table 4 to Table 7 (assuming $Q_{conv\,1} = 0$).

Table 4. Power Flow Result with Presence of UPFC.

<table>
<tr><th colspan="4">$r = 0.01\, pu\ and\ \gamma = 240°$</th></tr>
<tr><th rowspan="2">Bus number</th><th rowspan="2">Voltage amplitude (pu)</th><th colspan="2">Power losses</th></tr>
<tr><th>Active (MW)</th><th>Reactive (MVar)</th></tr>
<tr><td>1</td><td>1.06</td><td rowspan="14">4.86</td><td rowspan="14">14.83</td></tr>
<tr><td>2</td><td>1.045</td></tr>
<tr><td>3</td><td>1.01</td></tr>
<tr><td>4</td><td>1.011</td></tr>
<tr><td>5</td><td>1.015</td></tr>
<tr><td>6</td><td>1.07</td></tr>
<tr><td>7</td><td>1.046</td></tr>
<tr><td>8</td><td>1.09</td></tr>
<tr><td>9</td><td>1.028</td></tr>
<tr><td>10</td><td>1.013</td></tr>
<tr><td>11</td><td>1.037</td></tr>
<tr><td>12</td><td>1.055</td></tr>
<tr><td>13</td><td>1.052</td></tr>
<tr><td>14</td><td>1.04</td></tr>
</table>

Table 5. Power Flow Result with Presence of UPFC.

$r = 0.01\ pu\ and\ \gamma = 120°$			
Bus number	**Voltage amplitude (pu)**	**Power losses**	
		Active (MW)	**Reactive (MVar)**
1	1.06	6.16	18.82
2	1.045		
3	1.01		
4	1.009		
5	1.012		
6	1.07		
7	1.053		
8	1.09		
9	1.044		
10	1.026		
11	1.044		
12	1.061		
13	1.06		
14	1.079		

Table 6. Power Flow Result with Presence of UPFC.

$r = 0.015\ pu\ and\ \gamma = 120°$			
Bus number	**Voltage amplitude (pu)**	**Power losses**	
		Active (MW)	**Reactive (MVar)**
1	1.06	5.35	16.33
2	1.045		
3	1.01		
4	1.015		
5	1.017		
6	1.07		
7	1.065		
8	1.09		
9	1.065		
10	1.044		
11	1.053		
12	1.069		
13	1.076		
14	1.148		

Table 7. Power Flow Result with Presence of UPFC.

$r = 0.01\ pu\ and\ \gamma = 0°$			
Bus number	**Voltage amplitude (pu)**	**Power losses**	
		Active (MW)	**Reactive (MVar)**
1	1.06	8.6	26.25
2	1.045		
3	1.01		
4	0.999		
5	1.002		
6	1.070		
7	1.046		
8	1.09		
9	1.037		
10	1.021		
11	1.041		
12	1.058		
13	1.051		
14	1.053		

According to Table 4 to 7, if $r = 0.01\ pu$ and $\gamma = 240°$ the best answer can be obtained so that, power losses than base case (without UPFC) is decreased and voltage level of buses 4, 5, 9, 10 and 14 are increased.

5. CONCLUSION

This paper deals with the FACTS device known as the Unified Power Flow Controller that is used to maintain and improve power system operation and stability. The UPFC model for power flow studies that easier other models to implement in MATLAB is proposed. MATPOWER is used for UPFC modeling and simulation. The proposed model is tested on IEEE 14-bus system. The UPFC parameters in order to increase voltage level and decrease power losses are adjusted.

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Author Introduction

Sajjad Ahmadnia was born in Mashhad, Iran, in 1990. He received the B.S. degree in electrical engineering from the Sadjad Institute for Higher Education of Mashhad, Iran in 2012. Currently, His research interest is in FACTS devices and control.

Nasir Boroomand was born in Mashhad, Iran, in 1990. He has studied electrical engineering since 2009, from the Sadjad Institute for Higher Education of Mashhad, Iran in 2012 and he will receive B.S. degree in 2013. Currently, he has worked at the Khavaran Nasr Company. His research interest is in FACTS devices and control and simulate the FACTS Devices with MATPOWER software.

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